Decision Making in a Robotic Architecture for Autonomy

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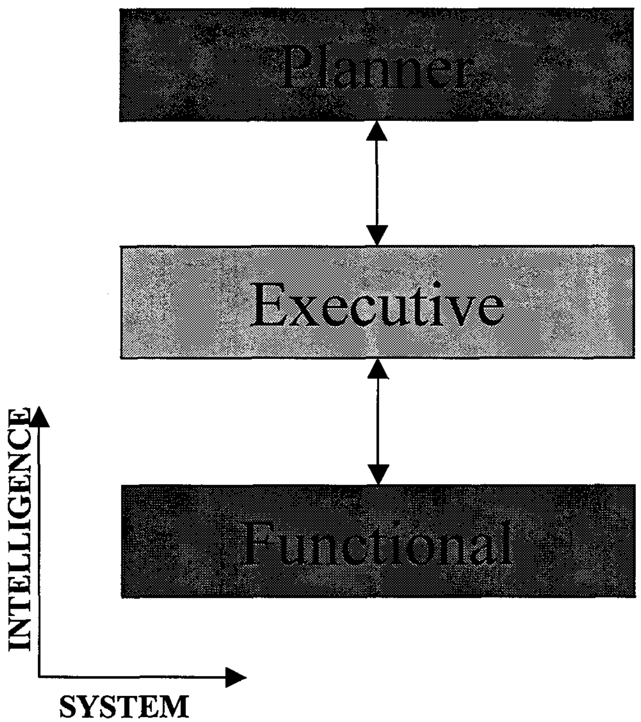
Background

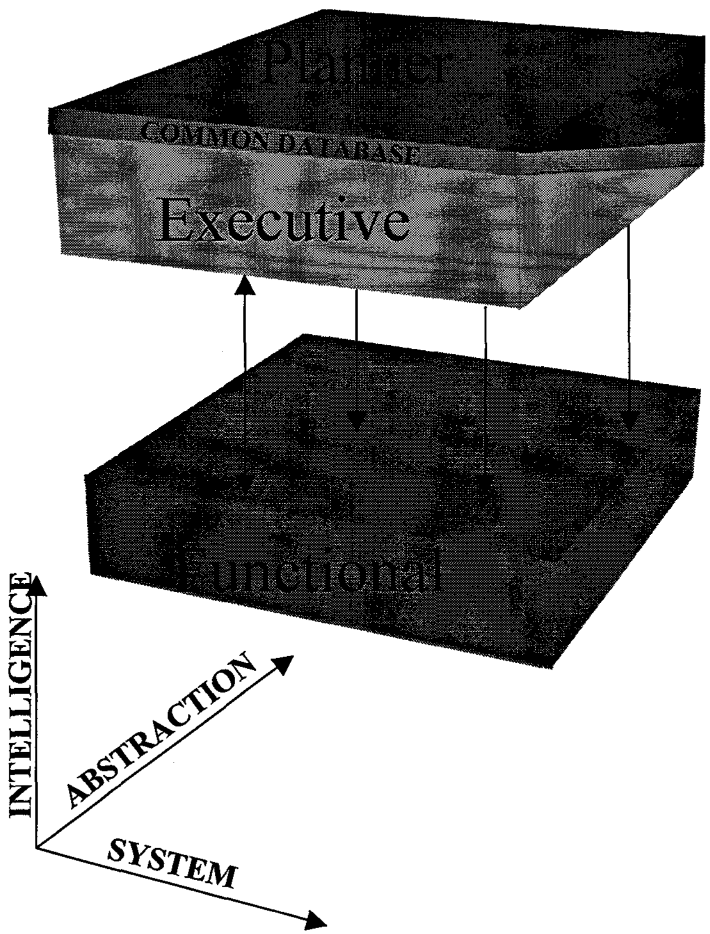
- CLARAty is an architecture for robotic control being developed at JPL
- CLARAty being designed to address future mission autonomy concerns
  - Many upcoming rover missions
  - Rovers will travel significantly farther distances requiring more autonomous capabilities
- Top layer of CLARAty provides autonomous decision-making and rover-sequencing capabilities (Primary focus of talk)
- Bottom layer provides basic robot functionality

Review of 3 Layer Approach



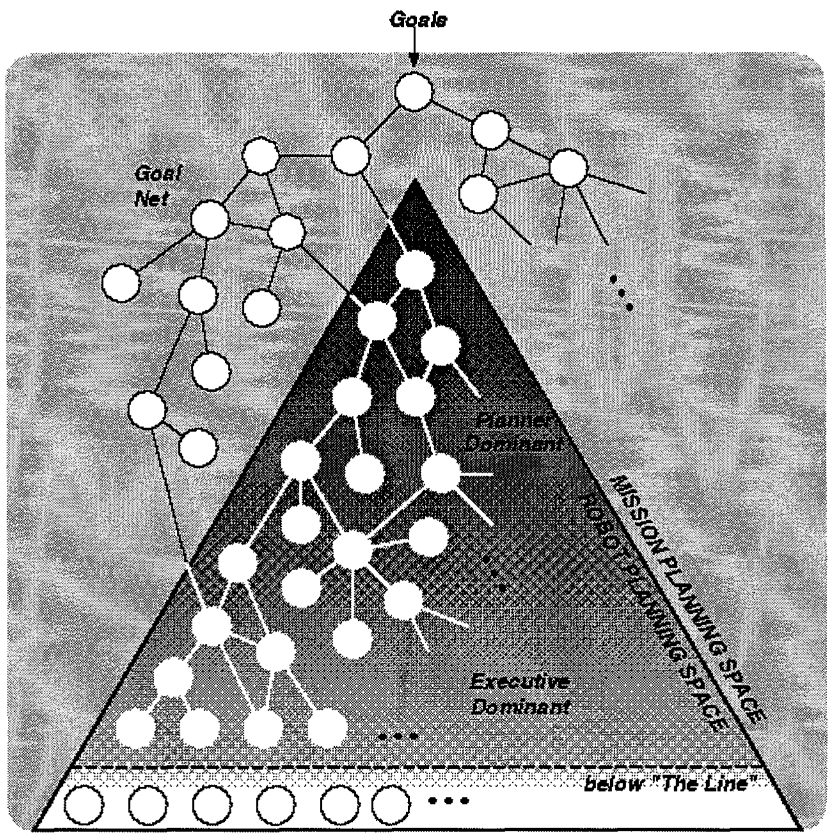
- Most past robotic architectures comprised of three layers
- Layers are organized by level of abstraction and intelligence in which they operate
- Several significant limitations
  - Each layer has separate representation and model of robot and environment
  - Creates unnecessary overhead to translate between layers and maintain separate models
  - Each layer also constrained to work at certain level of plan abstraction
  - Does not allow for use of new techniques which closely integrate planner and executive functionality

CLARAty Two-Layer Architecture



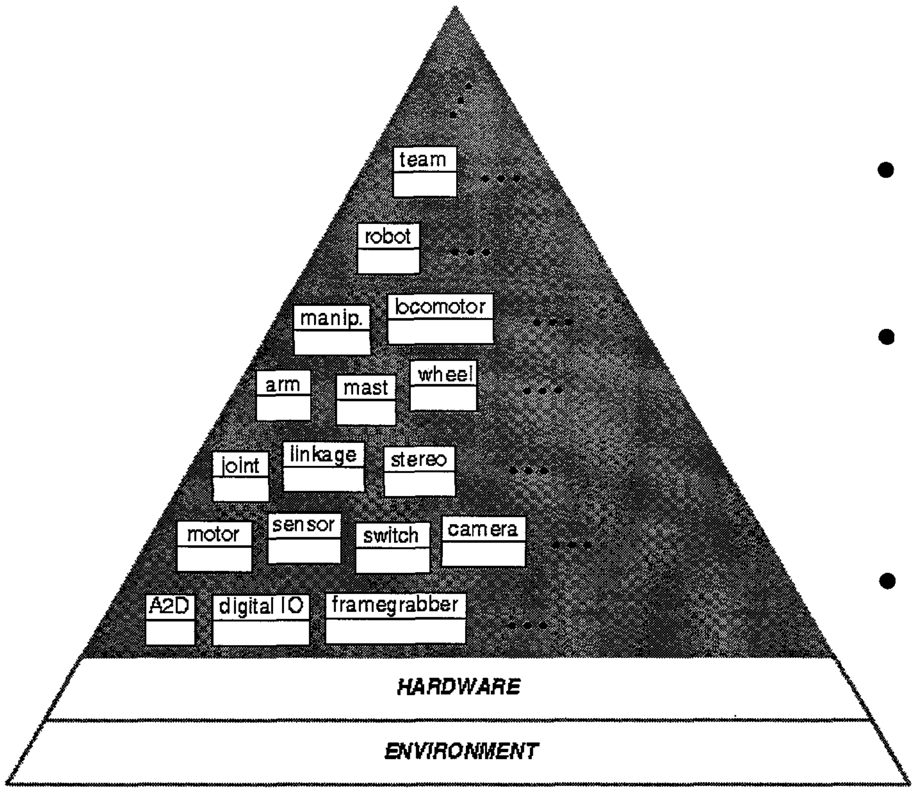
- Provides evolution to two-tiered architecture
- Each tier operates at all levels of abstraction
- Blends declarative and procedural techniques for decision-making
- Planner and exec can be closely integrated and even use common database
- Planning tier can access state and resource information contained in Functional Layer
- Interface between layers is flexible and allows user or domain to dictate capabilities used

Intro to CLARAty Decision Layer



- Breaks down high-level goals into a plan of activities
- Represents relevant mission and rover constraints (e.g., flight rules, resource limitations)
- Darker portion shows planner domain; lighter portion shows executive domain
- "The Line" separates DL from FL but can be moved
- DL interfaces to FL for commanding, monitoring and resource usage predictions

Intro to CLARAty Functional Layer



- Object-oriented design; FL can be structured to match modularity of hardware
- All objects contain basic functionality for themselves
- State of system is contained in objects and available through query
- Objects also contain predictive knowledge for relevant states and resources
- Designed to interface with rover simulators as well as actual hardware

Decision Layer Implementation

- Utilizes CLEaR (Closed-Loop Error and Recovery) System (Fisher, 2001)
  - Integrates planning and executive techniques
- CLEaR combines CASPER continuous planner (Chien, 2001) and TDL executive (Simmons, 1998)
  - CASPER provides capability for plan generation, limited execution, and re-planning
  - TDL provides full spectrum of executive-type capabilities (e.g., procedural expansion, activity execution and monitoring, exception handling, etc.)
  - CLEaR system intended to provide tightly-coupled approach to coordinating goal-driven and event-driven behavior

CASPER Summary

- CASPER: Continuous Activity Scheduling, Planning, Execution and Re-planning
- Provides continuous planning
  - Generates activity sequence that satisfies set of goals while obeying rover operation and resource constraints
  - Also monitors current rover state and plan execution status
  - Never allows plan to get very far out of sync
  - Utilizes "iterative repair" to repair conflicts that arise in plan by performing plan modifications
  - Can quickly re-plan if new conflicts or opportunities arise
- CASPER has been demonstrated in a number of robotic domains
  - e.g., landed ops for ST4 mission, control of DSN antenna ground station, distributed coordination of multiple rovers

TDL Summary

- TDL: Task Description Language
- Designed to perform robotic task-level control and/or to mediate between planner and rover control s/w
  - Expands tasks into low-level commands
  - Executes commands and monitors execution
  - Handles exceptions
  - Handles task synchronization
- Utilizes "task-tree" structure to describe how tasks (or activities) are broken down into commands
- Successful demonstrated on a number of indoor and outdoor robots
  - e.g., Nomad robot in Antarctica, RWI robot for Mars autonomy navigation

Current CLEaR Framework

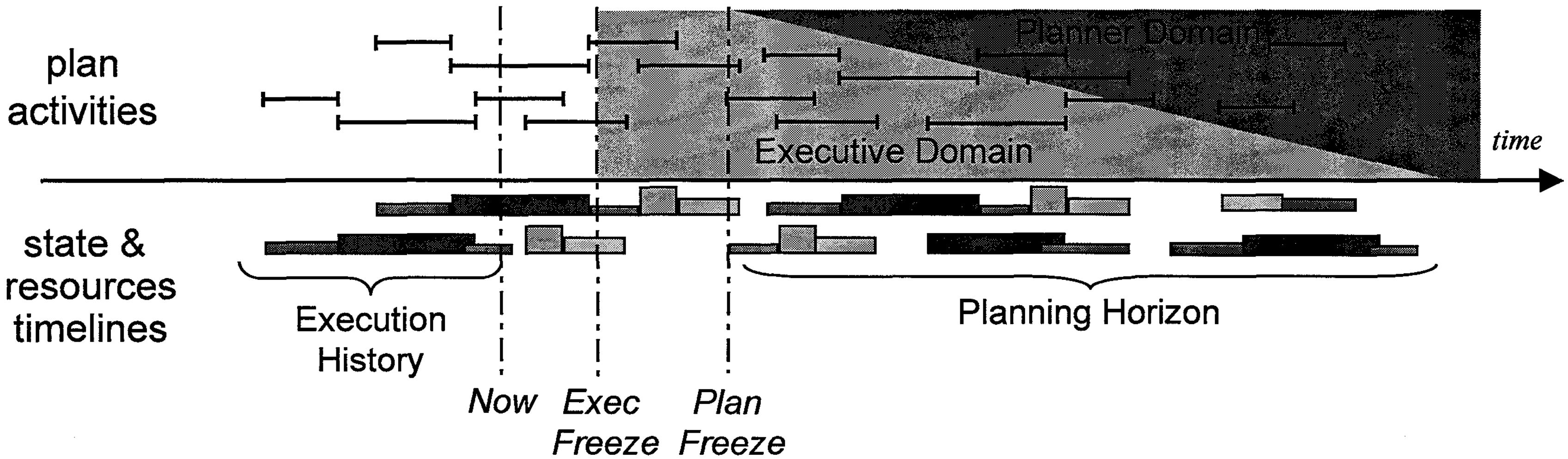
- CASPER and TDL loosely integrated
  - Systems maintain separate plan representations
  - Changes in one plan database can be reflected in other (e.g., TDL modifications can be seen by CASPER and vice versa)
- Decision process for deciding what system should handle conflict and how to coordinate plan changes
  - Can write heuristics to address certain decision types
  - For example,
    - Rover has to avoid unexpected obstacle and gets off-track of planned path
    - Planner and/or executive may react
    - May choose only one reaction or coordinate reactions from both systems

Future CLEaR Framework

- First step, tighten integration of CASPER and TDL
  - Enable CASPER to access procedural capabilities of TDL for initial plan generation and re-planning
  - Increase TDL's knowledge of plan resource levels and limitations; enable this knowledge to influence TDL decisions

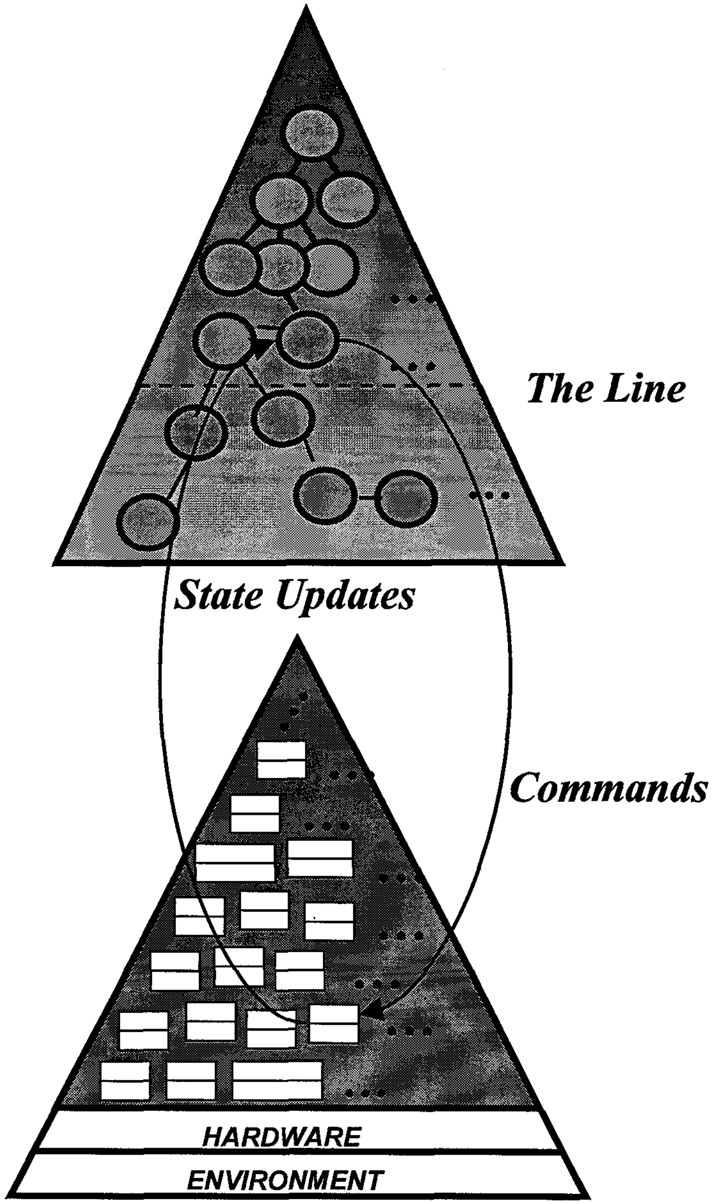
- Finally, fully integrate two systems
  - CASPER and TDL use shared plan representation and plan database
  - Only one domain model utilized by both systems
  - Enable both planning and executive functionality to be used at all levels of activity granularity

Final Planner and Executive Domains



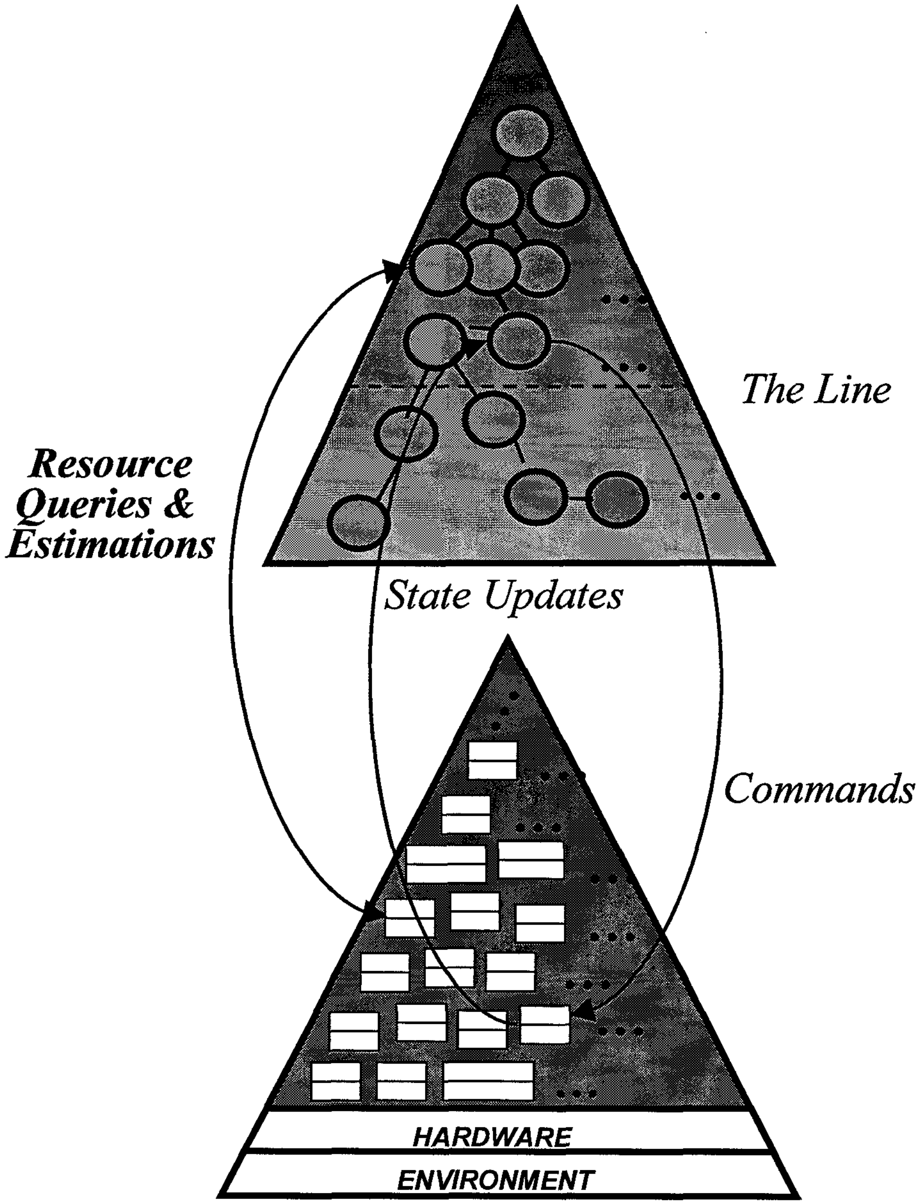
- No strict separation of planner and exec operation domains
- Procedural and declarative capabilities are allowed on both near-term and far-term activities
- Enables procedural constructs (e.g., conditionals, loops) to represent far-term activities
- Enables global-resource analysis to affect near-term decisions

DL Interface to FL: Floating Line



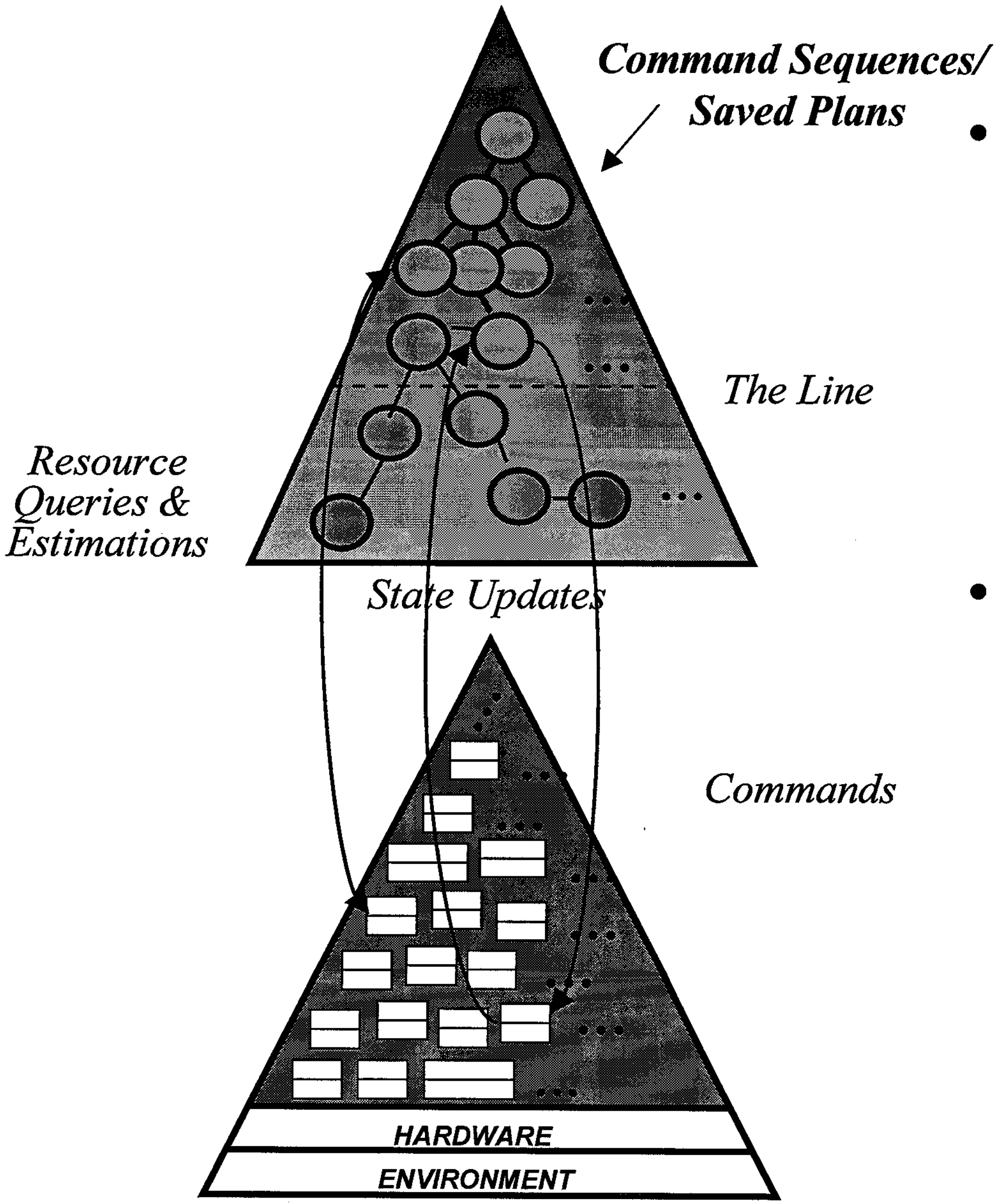
- Activities on fringe of plan network are dispatched to FL
- Status updates (for activities, states and resources) are received from FL
- Elaboration in DL can be to different levels of granularity
- Allowing a "floating line" enables level of control given to DL or FL to be flexible
- Line position can be user or application driven

DL Interface to FL: Resource Querying



- Information on resource usage is kept in FL
- DL can query FL for resource usage predictions
- Queries can be detailed or at a cursory level
- More detailed queries may requires more computational resources
- Queries can contain plan activity parameters and/or other relevant information

DL Interface to FL: Direct Commanding



- Command sequences can be submitted directly from ground ops
  - Simply executed by DL
  - No or minimal modification by planner and/or exec
- Plans or sub-plans can be saved and recalled at future times
  - Plans can be modified by planner to reflect current goals and state of system
  - State updates during execution may cause further modification

Related Work

- Remote Agent Experiment (RAX) (Jonsson, 2001)
  - Flown on NASA Deep Space One (DS1) mission
  - Utilized batch planner and executive to produce and execute command sequences
- Contingent Rover Language (CRL) (Bresina, 1999)
  - Allows both temporal flexibility and contingency branches in rover sequences
  - Produced by Contingent Planner (CPS) and then interpreted by Exec
  - Planner is ground-based; exec is onboard rover
- Other three-layer approaches (Bonasso, 1997; Gat, 1998)
- CPEF (Myers, 1998)
  - Related approach to combining planning and execution
  - Incorporates significant user guidance module (more ground-based)
  - Demonstrated for air-campaign plans

Conclusions

- CLARAty is a robotic architecture that provides autonomous rover control
- The CLARAty Decision Layer provides intelligent decision-making capabilities
  - Supports closely integrated planning and executive techniques
  - Produces and continually refines command sequences
  - Interfaces with Functional Layer in flexible fashion to provides different levels of DL capabilities
- CLARAty is currently being applied to several robotic efforts at JPL and is being directed towards future flight implementations